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SEDIMENT, STREAMFLOW, and LAND USE RELATIONSHIPS in NORTHERN LOWER MICHIGAN

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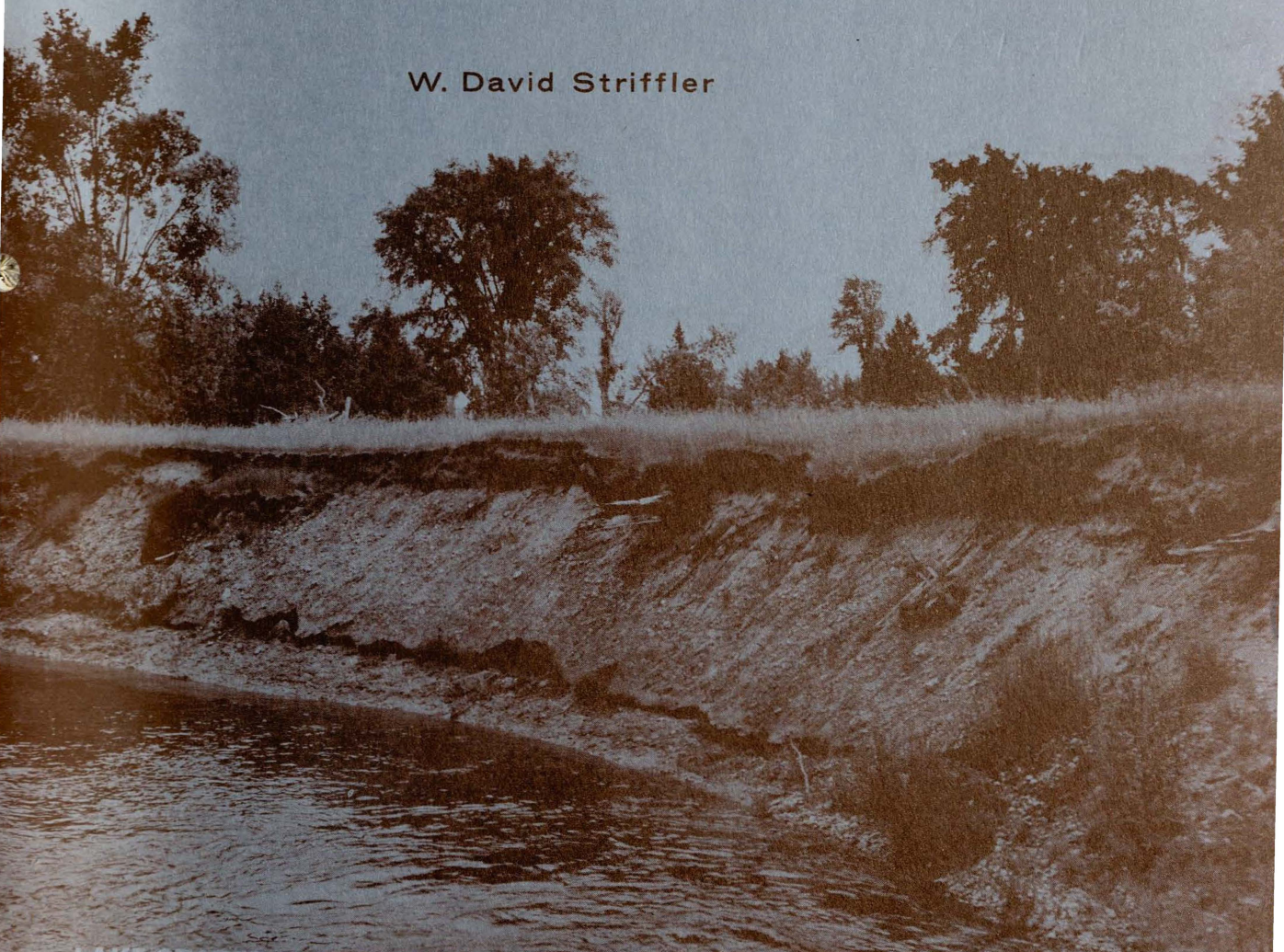

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Cover picture: A typical eroding bank, Tobacco River Watershed. Note scour line at the base of bank.

Introduction

Sediment in a stream can come from many sources and is influenced by many agencies. One of the most widely recognized influences is the way in which man uses the land. In general, the greater the disturbance to the watershed, the greater the effect upon streamflow and the greater the yield of sediment from the watershed. Many forms of disturbance have been recognized, including road construction, logging, agricultural practices, and grazing.

This paper reports the results of a study designed to evaluate the sediment contribution from the major land use types occurring within a typical mixed-use watershed in northern Lower Michigan.

Review of Literature

Stream sediment has been recognized as one of man's major land use problems since the days of the ancient Egyptians, Chinese, and Mesopotamians. The relationships between land use or abuse and the amount of sediment in the stream have been observed over the centuries. More than a hundred years ago, the effect of the removal of forest cover in particular was mentioned by Sir Charles Lyell (1849)[1]; on a trip to the United States he commented on the effect of forest clearing on the sediment loads. Ashe (1907) discussed the effect of forest clearing and soil type on sediment loads in the Potomac River and suggested that certain highly erodible soils within the watershed should not be cleared when slopes exceed a certain level.

During the conservation movement of the 1930's, runoff and erosion received considerable attention. A large share of the work concentrated on comparative erosion rates under various vegetative densities, cover crops, or other vegetative expressions (U.S. Dept. Agr. 1940). Relatively high erosion rates occur under open row crops (such as corn and cotton) while less erosion occurs from small grains, pasture, and hay land. Forest lands are generally recognized as having minimum soil losses.

Only recently, however, have modern statistical techniques made possible reasonable quantitative evaluations of watershed characteristics and conditions upon stream sediment yields.

Anderson (1949) found a close relationship between annual sediment accumulation in eight reservoirs and the maximum annual peak discharge, the area of the main channel, and the cover density on the watershed.

Anderson and Trobitz (1949) related peak discharge and sediment deposition resulting from a major flood to the area of barren land, maximum 24-hour precipitation, area of old fires, and an estimate of cover density. Twenty-five watersheds were analyzed.

In western Oregon, Anderson (1954) related the average annual sediment yield in 29 watersheds to 16 watershed factors. These included fixed factors such as area, channel gradient, soil erosibility, silt plus clay, and a surface aggregation ratio; hydrologic factors such as mean annual discharge and discharge

[1] *Names and dates in parentheses refer to Literature Cited at the back of the report.*

NOTE: At the time this study was made, the author was Leader of the Station's Ground Water Hydrology and Streambank Erosion Project at Cadillac, Mich. He has since been transferred to the U.S. Central States Forest Experiment Station. The study reported here was conducted in cooperation with the Michigan Department of Conservation. Acknowledgment is due the Michigan Water Resources Commission for assistance in preparing rating curves, and to Professor Robert Zahner, University of Michigan, for assistance in the programming and computer analysis of the data.

peakedness, an index of stream variability; and land use variables such as the portion of the watershed occupied by poor cover, poorly stocked forest, roads, recently cut-over forest, bare cultivation, other cultivation, and length of eroding banks. In this study, Anderson attributes the sediment yield from the Willamette Basin as being derived as follows: 54 percent from eroding banks, 24 percent from 5,460 square miles of forest land, and 22 percent from 1,820 square miles of agricultural land.

The Area

This study was conducted within the Tobacco River Basin in Michigan's Lower Peninsula (fig. 1). The Tobacco was selected for several reasons. First, the basin encompasses a part of both the northern forested region and the southern agricultural region of the State. Thus, within the basin occur broad areas representative of the major land use categories of Michigan. Second, the Tobacco River is composed of sufficient branches and tributaries so that a number of small sample watersheds could be selected for each land use type. And finally, eroding banks (one of the variables to be evaluated in the study) had become a serious problem in a number of the sample watersheds.

The watershed occupies an area of 276 square miles. The river has three main branches plus many smaller tributaries totaling about 207 miles of permanent channel. The upper portion of the watershed is forested. Streams originating here flow through

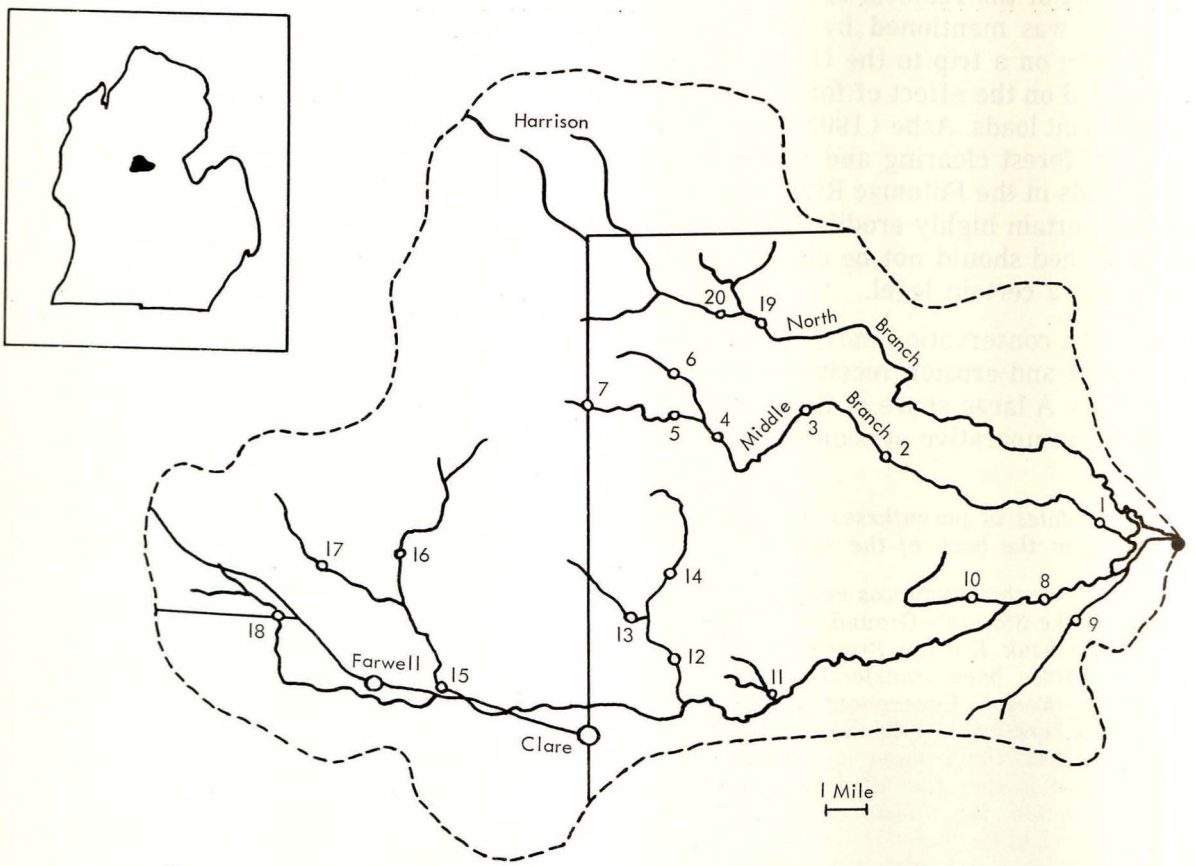

FIGURE 1. — Sampling stations within the Tobacco River Watershed.

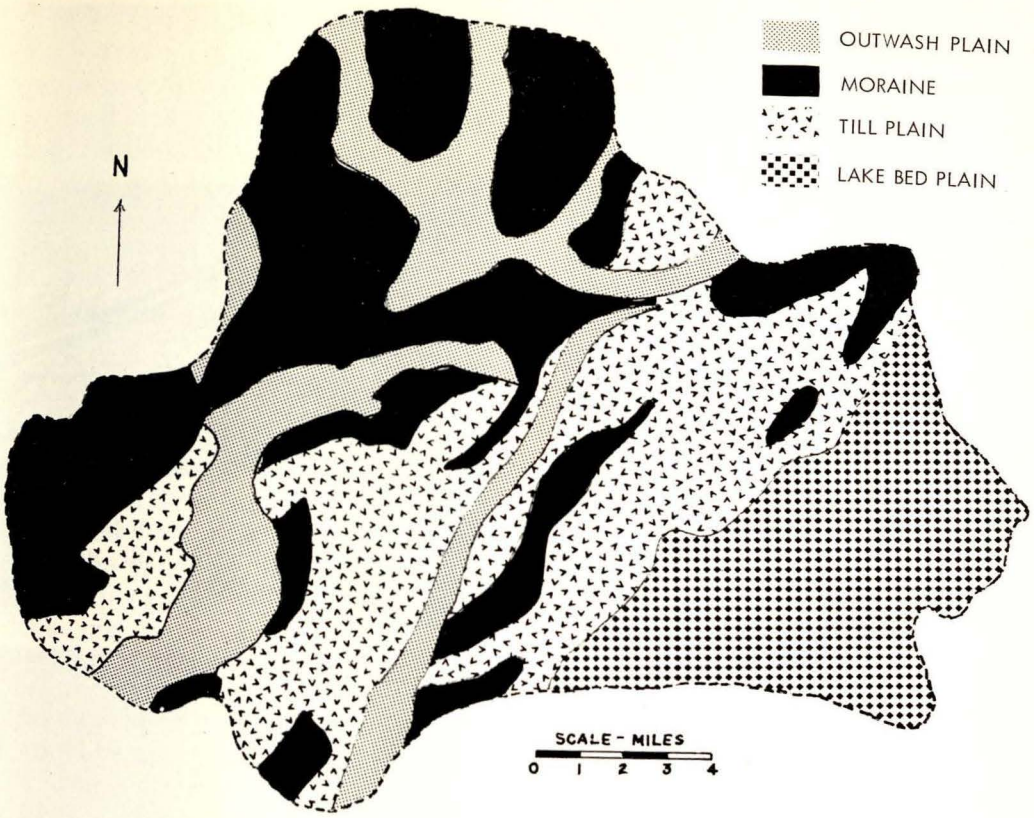

FIGURE 2. — Surface geology features, Tobacco River Watershed (after Martin 1955).

the agricultural lower watershed and finally empty into a reservoir at Beaverton. The headwaters portion of the three main branches has been classified as trout waters, while the lower portion is considered marginal in this respect.

The entire watershed is covered by a deep mantle of glacial drift (fig. 2). Four major types of surface deposits are commonly recognized. They include moraine, outwash plain, till plain, and glacial lake bed plain. The main streams flow successively through each of these types from west to east.

Within the morainal headwaters on the west the landscape is hilly to rolling, soils are sands or sandy loams, and streams are small and widely separated and exhibit uniform flow. Intermingled outwash plains consist of ancient glacial drainage channels where soils are largely stratified sands and gravels. Such deposits are generally level and form channels for present-day streams.

The till plain deposits occur within the central portion of the watershed. They vary from level to rolling and are composed of heavy clay and clay loam soils. Streams are more finely branched than in moraine or outwash areas and exhibit a wide range of flows during the year.

Lake bed plains occur in the eastern end of the watershed. These are broad, level plains with sandy surface soils underlain by lacustrine clays at varying depths. Surface drainage is almost nonexistent except for artificial drains and the main branches of the Tobacco crossing the plain.

Land use within the basin is closely related to the surface geology and soils. Moraines with deep sandy profiles and sandy surface soils are largely forested (fig. 3). Till plains are largely agricultural, with use divided between cultivated lands and pasture lands (fig. 4). Outwash plains are predominantly forested although they may be pas-

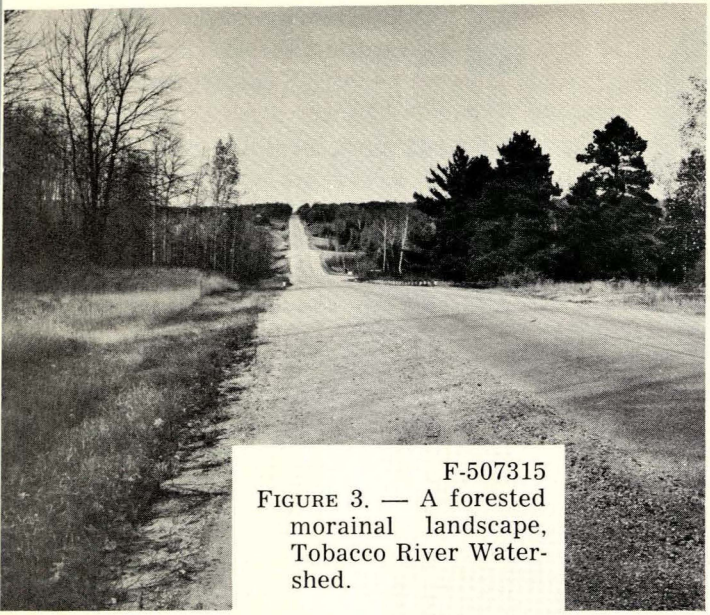

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FIGURE 3. — A forested morainal landscape, Tobacco River Watershed.

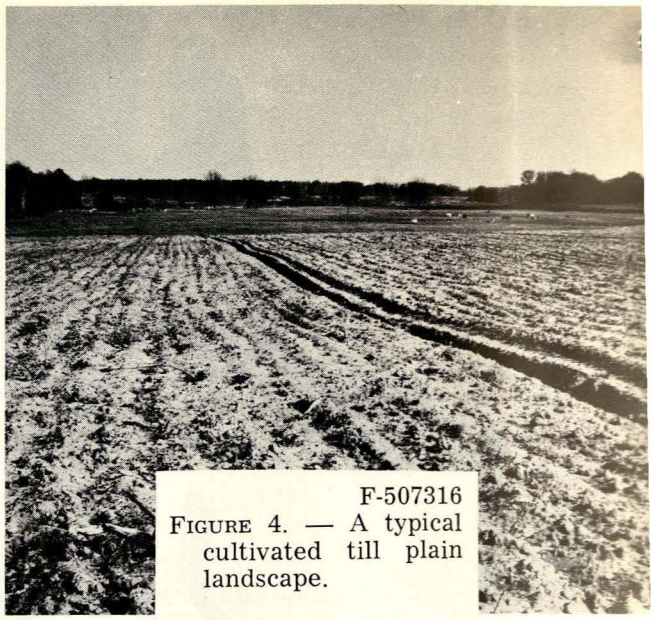

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FIGURE 4. — A typical cultivated till plain landscape.

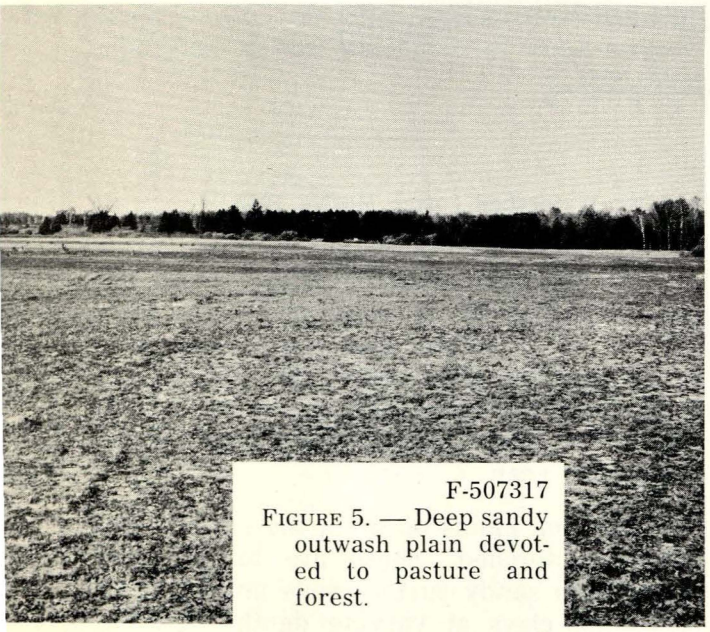

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FIGURE 5. — Deep sandy outwash plain devoted to pasture and forest.

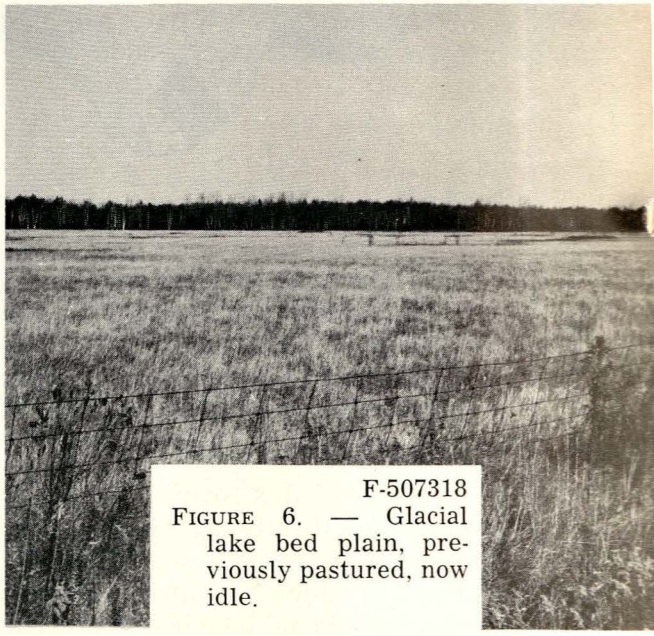

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FIGURE 6. — Glacial lake bed plain, previously pastured, now idle.

tured when they occur adjacent to till plain soils (fig. 5). The use of the lake plains depends upon the depth of the sand mantle and the drainage within a particular area. Where the clay beds come to the surface the land is cultivated, but where the sand mantle is deep or surface soils are wet, forest and pasture lands predominate (fig. 6).

Methods

In general, two areas can be identified as sources of sediment: eroding streambanks and upland erosion. Since upland erosion varies according to land use, a more detailed classification of sediment source areas is necessary. For this study, upland erosion areas were classified into major land use categories including cultivated land, pasture land, wild land, and forest land.

A secondary objective of this study was to relate streamflow variables to the same land use variables being considered as sediment source areas. Since erosion and runoff are closely related, a relationship between land use and the range of observed streamflows could help explain why erosion from certain land use types was greater than others.

An ideal method of explaining these relationships would be to select individual sample watersheds from within each of the major land use types. Unfortunately, small sample watersheds occupied by single-use types are the exception, while mixed-use watersheds of various sizes and shapes are the rule. To determine the sediment contribution from each land use type within a mixed-use watershed and how sediment varies with different proportions of each land use, a multiple regression analysis using observations from a number of mixed-use watersheds was selected as the best approach.

Twenty sample watersheds were selected, each representing different conditions with respect to size, land use, and other watershed characteristics. A staff gauge was installed on each stream, and a curve relating stream stage to discharge was prepared for each sample watershed. Sediment samples and stream discharge measurements were taken at irregular intervals between September 1960 and April 1962. Hydrologic events occurring included two snowmelt periods and several heavy rainstorms. During the study 840 sediment samples were collected, about half of them during snowmelt or stormflow periods. Instruments used were the US DH-48, US DH-59, and automatic single-stage sediment samplers. Each time a sample was collected, the stream stage was recorded and also whether the stream was rising or falling.

Sediment samples were analyzed by evaporating the moisture and weighing the residue. Organic components were first removed by oxidizing with hydrogen peroxide (H_2O_2). A correction for dissolved solids was also required. Sediment discharge rates were computed by multiplying the weight of the sediment per unit of water times the stream's discharge.

Land used for each of the sample watersheds was classified by means of aerial photographs and a field survey. Land use categories were defined as follows:

Cultivated land.—Included all land planted to an annual crop during the summer of 1961. Primary crops in the Tobacco River Watershed include corn, wheat, oats, other small grain, and a small percentage of row crops other than corn. It was assumed that these represented the total land area in the watershed that was plowed at least once a year.

Pasture land. — Included cattle pasture, sheep pasture, and a small amount of horse pasture. Hay lands were also included in this category since cutover hay lands are frequently pastured and generally have a continuous cover for 2 or 3 consecutive years.

Wild lands. — Included brush lands, nonforested bogs or swamps, abandoned land, and other idle lands. These lands were usually well vegetated by grass or other low vegetation and had little erosion potential.

Forest land. — Included all forest land, farm woodlots as well as broad forested areas. Forests were predominantly northern hardwood and oak-aspen with small areas of lowland hardwoods, swamp conifers, and coniferous plantations.

The multiple regression analysis was computed on the University of Michigan IBM 709/7090 computer, using a standard program known as the Westervelt Modified General Motors Multiple Regression Program. This is a stepwise analysis which selects and analyzes those variables most closely related to the independent variable. A multiple regression coefficient, coefficient of determination, and "F" level were computed for each variable entering the analysis. In this manner, only the most important variables were included in the analysis while variables entering the analysis at non-significant "F" levels were dropped. The significant variables in the study include stream discharge, rising or falling stage, eroding banks, and the individual land use variables. A separate equation was developed for each individual land use variable rather than for all variables grouped together.

Watershed characteristics are summarized in table 1.

TABLE 1. — *Summary of watershed characteristics for sample watersheds*

Station	Area	Eroding banks	Area in land use			
			Cultivated	Pasture	Wild land	Forest land
	Sq. miles	*100 ft.*	*Percent*	*Percent*	*Percent*	*Percent*
1	36.6	38	11	26	28	34
2	27.4	28	10	26	28	34
3	22.8	15	7	23	32	37
4	15.2	0	3	12	36	48
5	8.3	0	4	11	37	47
6	4.7	0	1	3	37	57
7	1.0	0	0	0	35	65
8	134.3	62	13	23	26	35
9	8.1	0	7	18	30	44
10	2.3	0	22	28	24	24
11	3.4	10	45	37	6	9
12	16.3	20	23	38	22	14
13	4.8	0	22	42	16	18
14	5.8	0	26	33	22	17
15	28.6	1	2	8	26	62
16	20.6	0	1	5	25	68
17	3.7	0	0	2	30	67
18	5.1	0	3	19	23	50
19	48.1	27	2	8	18	68
20	38.9	0	2	6	19	67

Land Use and Streamflow

Streamflow regimens are well known to be regulated by land use, soils, and other factors. In general, watersheds with fine-textured or shallow soils or cultivated lands have highly variable streams — that is, they exhibit low summer flows and high stormflow peaks. On the other hand, forest lands or watersheds with deep, coarse-textured soils generally exhibit higher summer flows and lower stormflows. These relationships were observed in this study.

Continuous streamflow records were not collected. Streamflow data consist of about 40 individual observations for each watershed, about half of which were taken during snowmelt or stormflow recession (table 2). Therefore, mean daily discharge values or frequency data cannot be extracted.

The range of observed discharge, however, very closely approaches the actual annual range of discharge. In the analysis, the range of observed discharge rates was used as an index of stream variability and was related to land use (fig. 7).

As shown in figure 7, the range (the difference between maximum and minimum flow) in stream discharges occurring within a watershed varies according to the proportion of the watershed occupied by the various land use types. Maximum discharge rates tend to increase as the area of cultivated and pasture land increases. Theoretically, a water-

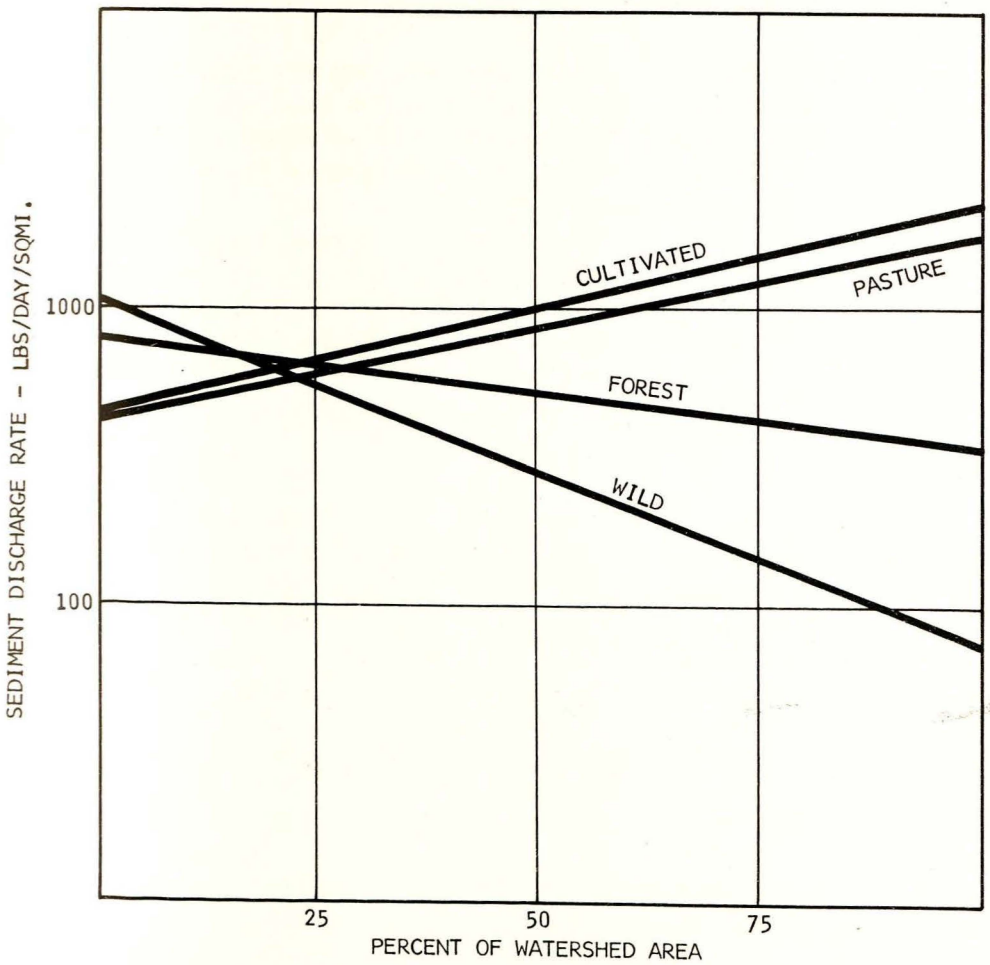

FIGURE 7. — Relationship between stream discharge variability and land use.

TABLE 2. — *Observed discharge rates, September 1960 through April 1962* (Cfs/sqmi.)

Station	Minimum	Maximum	Range	Mean
1	.505	5.500	4.995	1.455
2	.620	6.200	5.580	2.123
3	.613	6.132	5.519	2.084
4	.792	10.759	9.967	2.425
5	.993	3.717	2.724	2.200
6	.479	1.809	1.330	.904
7	2.900	10.000	7.100	5.754
8	.261	6.128	5.867	1.295
9	.001	5.700	5.699	.333
10	.022	12.320	12.298	2.277
11	.059	13.166	13.107	1.712
12	.154	5.682	5.528	1.185
13	.208	8.340	8.132	2.541
14	.017	4.862	4.845	.752
15	.454	3.195	2.741	1.261
16	.461	3.783	3.322	1.285
17	.137	1.616	1.479	.719
18	.119	4.198	4.079	1.057
19	.436	3.117	2.681	1.179
20	.459	5.736	5.277	1.316

shed entirely cultivated could have a spread in discharge rates of 85 cubic feet per second per square mile (cfs/sqmi.), while a watershed entirely pastured could have a range in discharge rates of about 50 cfs/sqmi. On the other hand, a completely forested watershed would theoretically have a difference of about 1.6 cfs/sqmi. between maximum and minimum flow, while a wild land watershed would have practically no variation at all (.13 cfs/sqmi.). Since watersheds of this nature (single land use type) are rare, the values quoted are entirely hypothetical. However, in the range of existing land use proportions, the observed ranges of flow fit the curves quite well.

Land Use and Sediment Discharge

The suspended sediment load in a stream at any one time is the result of two interrelated processes. These are (1) the erosion process involving the actual detachment of the soil particles, and (2) the transportation of the sediment particles. Both of these processes affect the amount of sediment in the stream. For example, a short intense summer storm may cause considerable erosion in a field but, if there is not enough runoff to carry the soil material into the stream, it will be redeposited downslope and stream sediment concentration may not be greatly affected. On the other hand, if large volumes of water become available (such as occurs during a snowmelt period) the transporting ability of the runoff will be great compared to the amount of sediment removed and sediment concentrations will remain lower than normal for the volume of runoff. The more common situation would be for both streamflow and sediment discharge to increase simultaneously.

An earlier analysis (Striffler 1963) indicated that sediment concentration in the Tobacco River is related to stream discharge and to whether the stream is rising or falling. Since these two variables explain a considerable portion of the total observed variation (31 percent) without obscuring land use effects, they were included in the analysis (fig. 8).

The multiple regression equations derived thus include two streamflow variables (stream discharge = Q, and rising and falling stage = R/F), the length of eroding banks (EB), and individual land use variables.

(1) $\log Sed_Q = 3.100 + 1.288 \log Q - .573\ R/F + .182 \log EB + .007$ cultivation ($R = .84$)

(2) $\log Sed_Q = 3.059 + 1.286 \log Q - .568\ R/F + .168 \log EB + .007$ pasture ($R = .84$)

(3) $\log Sed_Q = 3.482 + 1.289 \log Q - .584\ R/F + .189 \log EB - .012$ wild ($R = .84$)

(4) $\log Sed_Q = 3.329 + 1.281 \log Q - .569\ R/F + .179 \log EB - .004$ forest ($R = .84$)

The relationships between sediment discharge rates and land use are illustrated in figure 9. Sediment discharge rates increase with increasing proportions of cultivated and pasture land and decrease with increasing proportions of forest and wild land. Cultivated land yields slightly more sediment than pasture land, all other conditions being equal. For example, a watershed completely cultivated would have an average sediment yield rate of 2,200 lbs/day/sqmi. while a pastured watershed would yield 1,800 lbs/day/sqmi. (fig. 10). An earlier analysis of the data indicated that pasture land had a greater sediment yield rate than cultivated land (Striffler 1963). However, by placing the individual land use variables into separate equations, the reverse becomes clear.

Forest and wild land yield sediment at substantially lower rates than either cultivated or pasture land. Forest land had an

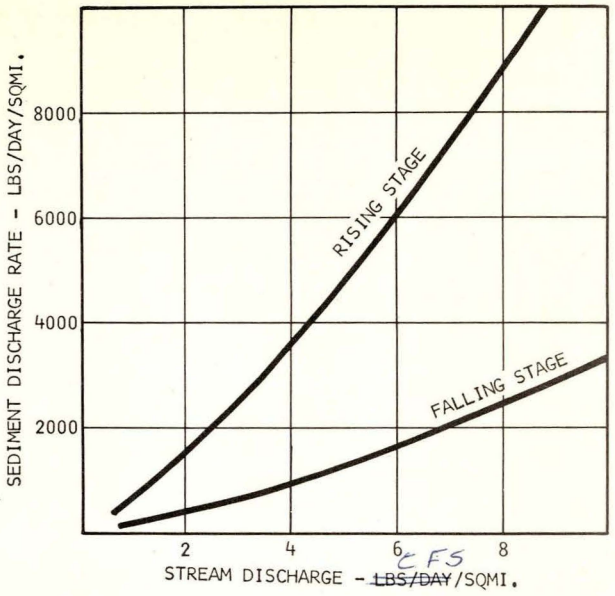

FIGURE 8. — Relationship between stream discharge and sediment discharge rate.

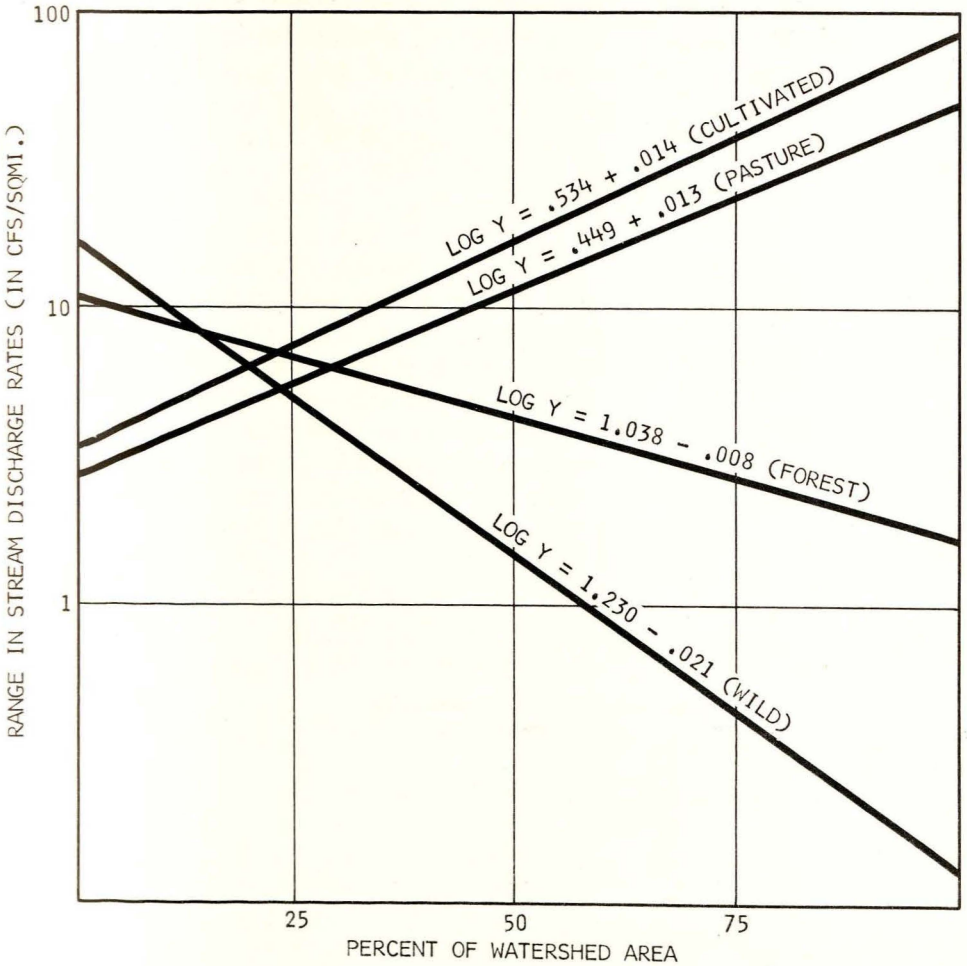

FIGURE 9.—Relationship between ~~sediment~~ discharge rates and land use.

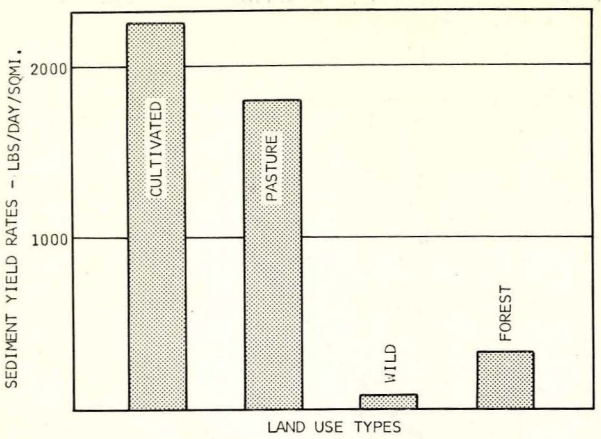

FIGURE 10. — Average sediment discharge rate by land use types.

average sediment yield rate of 360 lbs/day/sqmi., while wild land had an average sediment yield rate of about 74 lbs/day/sqmi. (fig. 10). The lower yield rate from wild land is probably because of the large areas of bogs and brush-covered swamps (areas which would have almost no erosion) whereas forest land included sloping land and a number of farm woodlots on heavy soils, which would produce more sediment.

In the Tobacco River Watershed, the average sediment load can be attributed to the various sources as follows:

	Percent
Eroding banks	33
Cultivated land (10 percent of area)	15
Pasture land (18 percent of area)	24
Wild land (26 percent of area)	5
Forest land (44 percent of area)	23

Land use in northern Lower Michigan is closely related to the soils and geology. Because of this close relationship, the results of this study as expressed in the equations must be used with caution. The land use variables as used and discussed do not yield a simple sediment land use relationship but rather an integrated relationship with land use and its associated soils or geologic features. The equations derived express the average situation as it now occurs and cannot be used to predict the effects of a land use change.

Eroding Banks

Eroding banks within the watershed are an important source of suspended sediment. In the 20 sample watersheds, an average of 33 percent of the measured suspended sediment load is attributed to eroding banks (see cover picture). This proportion varies among the sample watersheds according to the length of eroding bank (fig. 11).

The importance of eroding banks as a sediment source suggests that suspended sediment loads might be substantially reduced through bank stabilization treatments. Of the seven sample watersheds with important bank erosion problems, estimated potential sediment reductions range from 54 to 35 percent (table 3). Whether such reduction can actually be attained remains to be tested.

TABLE 3. — *Predicted sediment reductions by stabilizing eroding banks*

Sample watershed	Eroding banks	Average sediment	Predicted sediment	Potential reduction
	100 ft.	*Lbs/day/sqmi.*	*Lbs/day/sqmi.*	*Percent*
1	38	690	360	48
2	28	640	350	45
3	15	550	330	40
8	62	780	360	54
11	10	960	620	35
12	20	750	430	43
19	27	560	310	45

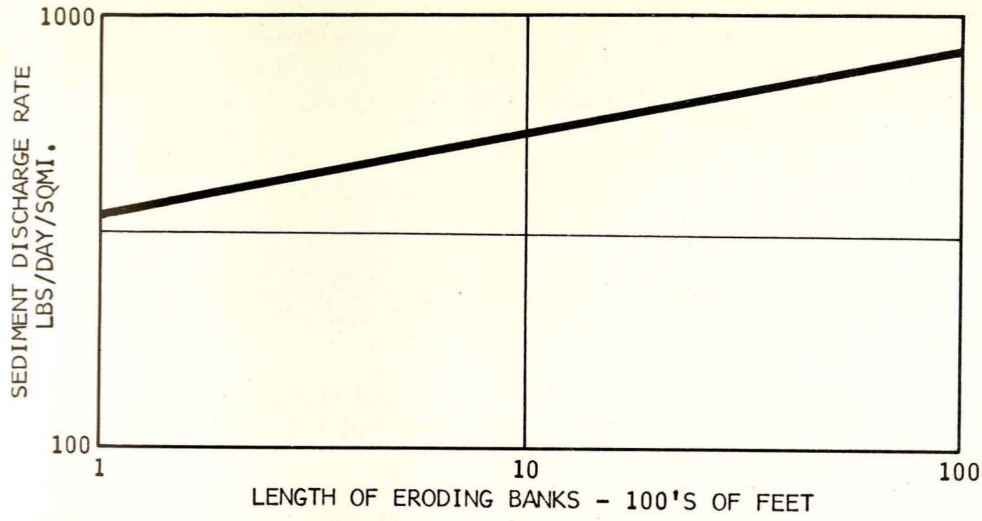

FIGURE 11. — Relationship between length of eroding banks and sediment discharge rate.

Summary and Conclusions

In the Tobacco River of northern Lower Michigan, both streamflow variability and sediment discharge rates are related to land use. These relationships are due partly to the land use factor and partly to the soil types generally associated with specific land use categories. Cultivated and pasture lands, which receive annual disturbance in the form of plowing or grazing and which are largely confined to finer textured till plain soils, demonstrate extreme variability in both stream discharge rates and sediment discharge rates. On the other hand, forest and wild lands, which are comparatively undisturbed and which are generally associated with coarse-textured soils, have unusually stable stream discharge rates and are relatively low sediment contributors.

These relationships were determined for the Tobacco River Watershed by means of a multiple regression analysis of sediment and streamflow observations taken from 20 sample watersheds each representing varying conditions with respect to land use and degree of bank erosion. Results may be summarized as follows:

1. Cultivated land occupying 10 percent of the watershed and with an average sediment yield rate of 2,200 lbs/day/sqmi. contributed 15 percent of the average observed suspended sediment load. The range of stream discharge rates could theoretically show a spread of 85 cfs/sqmi. from a completely cultivated watershed.

2. Pasture land occupied 18 percent of the watershed and had an average sediment yield rate of 1,800 lbs/day/sqmi. Twenty-four percent of the average sediment load was attributed to pasture land. The range in stream discharge rates from a completely pastured watershed could theoretically differ by 50 cfs/sqmi.

3. Wild land was the lowest sediment contributor of all land use types, contributing about 5 percent from 26 percent of the area. The average sediment yield rate was 74 lbs/day/sqmi. Streamflow observations from wild land watersheds would theoretically vary less than 1 cfs/sqmi. The low sediment yield rate and unusually stable flows are probably due to the large areas of nonforested swamps and bogs included in the wild land classification.

4. Forest land was also a low sediment producer, contributing 23 percent of the average sediment load from 44 percent of the area. The average sediment yield rate from a forested watershed would be about 360 lbs/day/sqmi., while streamflow would have an annual variation of about 1.6 cfs/sqmi.

5. Eroding banks are an important sediment source. In this study, about one-third of the average suspended sediment load is attributed to eroding banks. The importance of eroding banks suggests that substantial sediment reductions could be achieved through bank stabilization.

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